Sensitivity of Acoustic Scattering Models to Fish Morphometry

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Abstract: Current efforts to model fish backscatter use digitized images of fish anatomy to realistically represent swimbladder shape, volume and aspect. X-rays images of Atlantic cod (*Gadus morhua*) were digitized at high resolution to examine the effect of varying image resolution on predicted backscatter as a function of carrier frequency and swimbladder shape. Backscatter amplitude scattering curves diverge with decreasing image resolution and increasing carrier frequency in the geometric scattering region. Image resolution has less effect on backscatter amplitude variability at/near resonance than in the geometric region.

INTRODUCTION

Anatomically based theoretical models and imaging technology allow predictions of acoustic backscatter from high resolution images of fish morphometry. An assumption is that higher resolution leads to better predictions of acoustic backscatter. This has not been tested, and the effects of image resolution on the variability of scattering predictions need quantifying. High resolution images of fish body and swimbladder morphometry were used in a Kirchoff Ray-Mode scattering model (KRM) (1). The KRM model converts fish morphometry to equivalent cylinders, for calculation of acoustic backscattering. Details of the KRM model can be found in (1) and (2). This paper quantifies effects of image resolution on backscattering amplitude and suggests procedures for using digital images in scattering models.

METHODS

Dorsal and lateral x-ray images of nine, surface adapted, Atlantic Cod (*Gadus morhua*) were acquired using a Hewlett-Packard 43805N/P Faritron x-ray machine at the following settings: 42cm focal length, 40-45 kVp power and exposure times of 1-2 minutes. Digital representations of the fish body and swimbladder were obtained from x-ray film by hand-tracing the outer edges of the fish body (not including fins) and swimbladder, scanning the traces with a computer scanner and digitizing the traces at a resolution ($\mathcal{R}$) of 1mm along the axis of the fish body using an automatic algorithm. Lower resolution images were obtained by re-sampling the body and swimbladder at equal intervals of 2 to 20 mm. For resolutions courser than 20 mm, intervals at 5% of the swimbladder length were used, to a lowest resolution of one-half the swimbladder length. Reduced scattering length as a function of L/λ (L is fish length, often Total or Standard length, and λ is acoustic wavelength), was computed for whole-fish backscatter (swimbladder and body added coherently (1)) for each resolution. Effects of image resolution on backscatter were quantified in two scattering regions: Rayleigh to resonance region (100Hz-5 kHz) and the geometric scattering region (5kHz-200 kHz). Cod were scaled to their mean length (253 mm; range 147-391 mm) for model calculations at an aspect of 90°.

LOW FREQUENCY

Swimbladder volume decreased as image resolution decreased (Figure 1). The maximum reduction in volume was nearly 40%, with most individual reductions near 30%. Correspondingly, resonance peak frequencies increased with decreasing image resolution. Peak frequencies ranged from 190-510 Hz, and increases ranged from 40-260 Hz within individuals as resolution decreased. Maximum amplitudes of the resonance peaks ranged from -35.4 to -33.1 dB, with individual variation of <1 dB. The resonance quality factor (Q) (resonance f_{peak} [Hz]/peak-width [ΔHz]) has been used as a quantifiable parameter to characterize resonance scattering for individual fish and aggregations (3). The Q-factor showed no discernible trend as a function of resolution, suggesting Q may be a stable parameter for characterizing cod backscatter in the resonance region (Figure 2). At low frequencies, scattering amplitudes depend only on swimbladder volume (KRM model). Thus fish images should be sampled at a resolution to accurately characterize the swimbladder volume. In general, effects of image resolution on scattering amplitudes were considerably less in the resonance region than in the geometric region. This indicates that parameters such as the Q-factor or a Diagnostic Frequency Ratio for targets such as fish (ratio of transition frequency to L) may be optimal for separating scattering types in the resonance region.
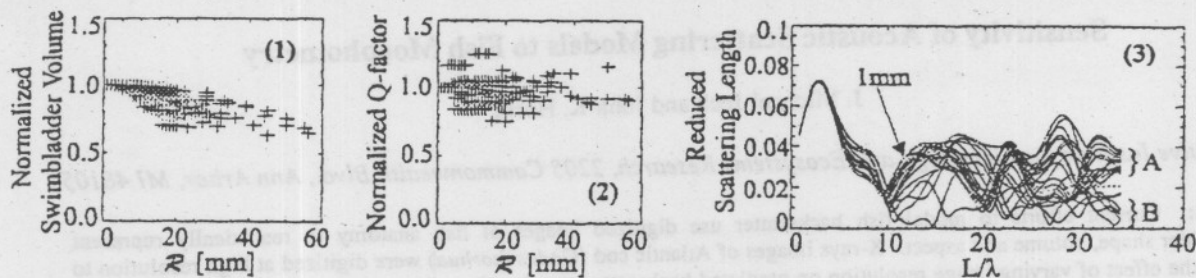
FIGURE 1. Normalized $(\mathrm{Vol}(\mathcal{R}_{mm})/\mathrm{Vol}(\mathcal{R}=1\mathrm{mm}))$ swimbladder volume for all cod. Volume normalization incorporates absolute differences in swimbladder volumes, allowing for inter-cod comparisons. Note that image resolution along the abscissa represents interval sample spacing and lowest resolution is on the right hand side of the graph (also for Figure 2).

FIGURE 2. Normalized $(Q(\mathcal{R}_{mm})/Q(\mathcal{R}=1\mathrm{mm}))$ Q-factor of the resonance peak for all cod. Q-factors were normalized to allow comparison between cod. Note that the + symbols do not represent range, only the data value.

FIGURE 3. Twenty five scattering amplitude curves for a single representative cod at image resolutions of $\mathcal{R}=1$ mm (thicker line denoted by arrow) to $\mathcal{R}=31$ mm. A L/λ ratio of $20 \approx 120$ kHz, for the 253 mm scaled cod (original length: 213 mm). A and B denote clustered scattering amplitudes at 200 kHz ($L/\lambda = 34$).

HIGH FREQUENCY

Backscatter amplitudes above $L/\lambda=5$ (30 kHz), diverge with decreasing image resolution and increasing frequency (Figure 3). Variance in reduced scattering length was minimal below $L/\lambda = 5$. As image resolution decreased, deviations from the $\mathcal{R}_{mm}=1$ curve started at higher frequencies. For image resolution of $\mathcal{R}_{mm}=3$, divergence initiated at $L/\lambda\approx27$, followed by divergence at $L/\lambda\approx15$ for $\mathcal{R}_{mm}=6$, then at $L/\lambda\approx9$ for $\mathcal{R}_{mm}=10$. The general trend of increasing divergence at higher frequencies parallels that found by increasing cylinder roughness (4). To model this divergent trend, the amplitude and phase components of the scattering model were modified to include a 'resolution factor' analogous to roughness in (4). The 'resolution factor' was set equal to $\exp[-ks(\mathcal{R}_{mm})]$ (1), where k is the wave number ($2\pi/\lambda$) and s is the rms deviation of the swimbladder upper surface from the 1 mm image resolution. Dorsal swimbladder scattering is dependent on only the top face of the swimbladder in the KRM model. $s(\mathcal{R}_{mm})$ was computed at each resolution, and then applied to the $\mathcal{R}_{mm}=1$ image. rms deviations for the cod in Figure 3 ranged from 0 to 1.1 mm, with a maximum deviation for the nine cod of 1.4 mm. Scattering amplitudes calculated with the resolution factor were generally comparable to the original coarse resolution curves. This suggests image resolution can be characterized by the rms deviation analogous to the use of cylinder roughness.

An echo amplitude Probability Density Function (PDF) at 200 kHz ($L/\lambda=34$) would show a bimodal distribution (Figure 3, amplitude regions denoted by A and B). A PDF spanning the full range of backscattering amplitudes at this frequency is not entirely explained by a Rician PDF, although each mode may be modeled as a separate PDF. Small changes in swimbladder shape, as measured by the rms swimbladder deviation, may account for bimodal echo amplitude PDF's (e.g. (2)) and generally broader PDF's found in target strength measurements (5) at high frequencies.

ACKNOWLEDGEMENTS

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